Exhibit 12

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Environmentally Friendly Quantum Dots for Display Applications

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SAIT, Samsung Electronics

QD Forum 2018/March/13th

Contents

Quantum Dots

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- The active technology for the past 35 years

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'02 QD PV (Alivisatos)

'98 Bio Labeling (Alivisatos)

'09 Full color QLED (Samsung)

'00 QD LED (Bawendi)

'15 Cd-free QD TV (Samsung)

'02 QD-LED (Bulovic)

'99 printable TFT (Jacobson)

'04 Memory (Bawendi)

'10 QD-LED TV (Samsung)

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Samsung Challenge

'80 '90 '00 '10

'81 Quantum size effect

'92 GaAs synthesis (Alivisatos)

'93 Monodisperse (Murray)

'96 Core/Shell (Heins)

'99 Blinking (Brus)

'00 Shape control (Alivisatos)

'00 Doped QD (Bawendi)

'03 SILAR (Peng)

'07 InP/ZnS (Peng)

'11 Blinking (Klimov)

Trends

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Wide color gamut display with RoHS compliant materials

Form	'13	'14	'15	'16	'17
QD Rail (Cd)	QD Vision (Boston, 200kg) Cd-QD SONY (TV, 13 line-up)	TCL (TV)	Philips, BOE (Monitor) Hisense, Konka (TV)		Samsung M&A
QD Film (Cd/Cd-free)	Nanosys: Cd-QD (Milpitas, 2000kg) Cd-QD 3M (QDEF) Amazon (Kindle) ASUS (Laptop) Najing Tech (Cd QD) Nanoco/Dow Chem. (Mass Production) Cd-free QD '10 QD-LED TV Samsung proto	Hisense (TV) TCL (TV) Vizio, AUO (TV) Samsung (SUHD TV) Cd-free QD	LMS/Hitachi (QDEF) QMC/Nitto Denko (Film) Wah Hong (Film) Nanoco/Merck (Mass Production)	ASUS (Monitor) Sangbo (Film) Poly-OE (Film) TCL (TV) Hisense (TV) Samsung (QLED TV)	Cd-free QD Dongwoo Finechem DIC (Color filter) Samsung (Monitor)
RoHS	Exemption#39 → expire July '14	Exemption#39 (lighting) → extend to July '17	Exemption#39 → EP Veto (May '15)	Exemption#39 replace → CdSe QDs color converting display (2 years) → Expire for all categories on Oct. '19	

Cd-free QDs

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- Alternatives : Emission range, QY, FWHM, Reabsorption, Decay time
  → InP, ZnSe:Mn, CuInS2

Table III. Comparison of typical properties of Cd-based and non-Cd QD composites. *ECS J. SS Sci. & Tech.(2013) Nanoco*

	Intrinsic QDs		Other non-Cd QDs	
Property	Cd-based QDs	Non-Cd QDs	Doped non-Cd QDs	Non-Cd alloy QDs
Chemical composition	CdSe/ZnS	InP-based core-shell	ZnSe:Mn/ZnS	$CuInS_2$/ZnS
Emission color	Tunable in VIS	Tunable in VIS	Yellow-orange	Tunable (Y,O,R)
FWHM (nm)	<40	40-60	~155	~125
Toxic substance	Toxic (Cd)	no Cd, no Pb	no Cd, no Pb	no Cd, no Pb
Stokes shift (meV)	~40[85]	~80[86]	~1060–1423[9,87]	~500-600[11]
Reabsorption	Reabsorption/self-quenching (small Stokes shift)		No reabsorption /self-quenching (large Stokes shift)	Some reabsorption/self-quenching (moderate Stokes shift compared to doped QDs)

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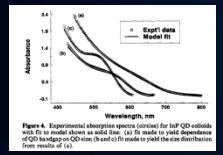
InP-based QDs

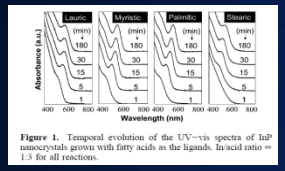
High quality core → Core/Shell → Multi shell

JPC ('94) Nozik



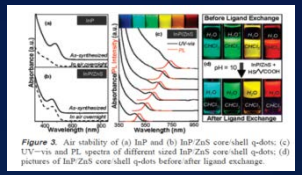
InP precursor with TOPO
270 C, 3 days

NL ('02) Peng



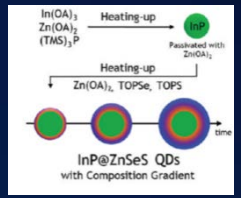
In(OAc) + acid ligand,
ODE, 270 C, 180min

JACS ('07) Peng



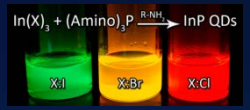
C8 amine, 180 C
→ 450~750nm, QY=40%

CM ('11) Char



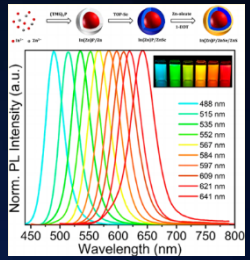
InP/ZnSeS gradient shell
QY=70%, FWHM=45nm

Chem. Mater. ('15) Hens



InCl3+Aminophosphine

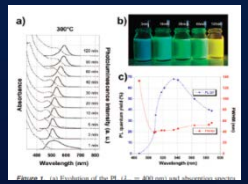
CM ('17) Lee



FWHM : G 36nm, R 45nm

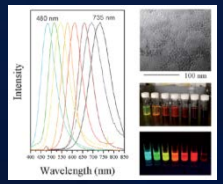
1990 2000 2010 2020

JACS ('08) Reiss



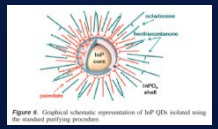
InP/ZnS One pot
(510~580nm) QY=70%,
~50h photo stability

JMC ('08) Nann



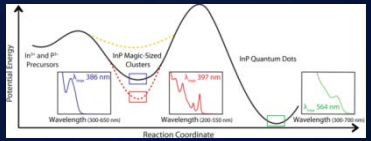
Zn, HAD → size control
(480~750nm)

JACS ('10) Delpech



PO4, InPO3, acid ligand
→ Ketone & Water

CM ('15) Cossairt



Magic sized cluster

Progress of Materials

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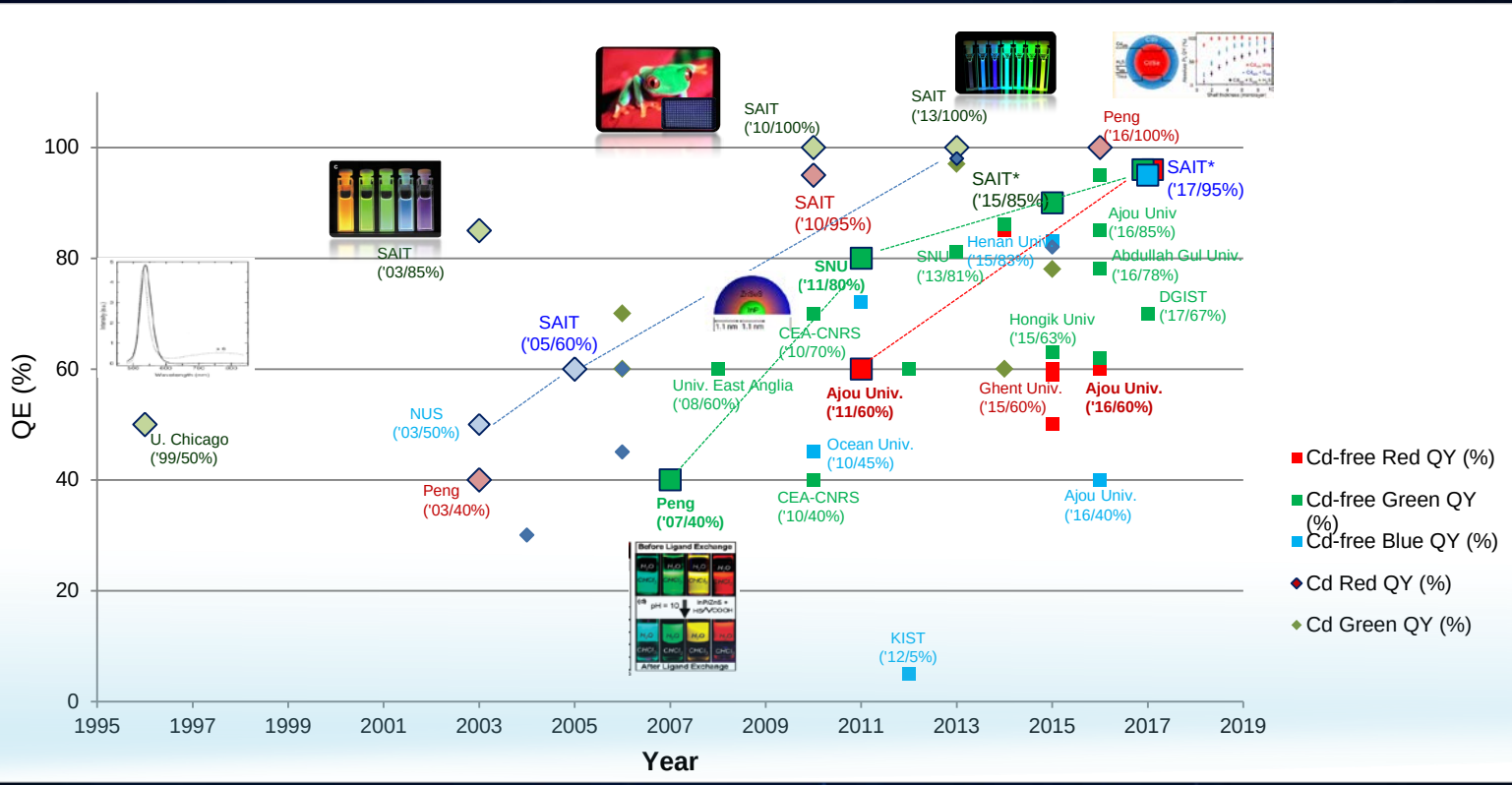
Progress in QE of QDs



Material Synthesis

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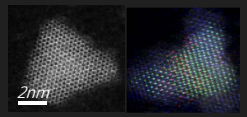
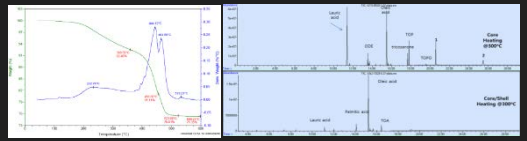
Specifically tailored structure for light emission



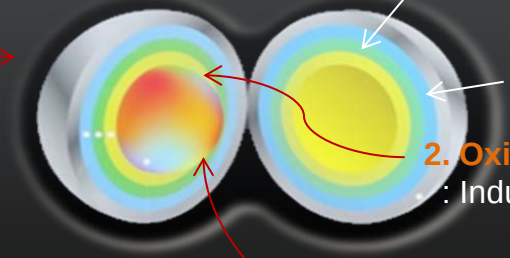
3. Crystallinity
(High temperature growth)

4. One pot synthesis with high concentration



5. Control the uniformity of size/shape and the byproducts
*(*P)*

1. Multi element core/Gradient shell structure

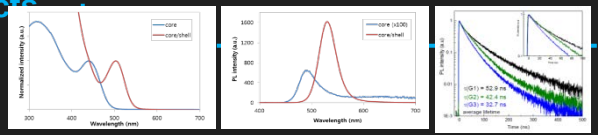


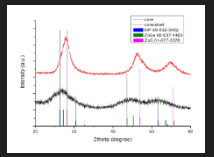
ZnSe rich

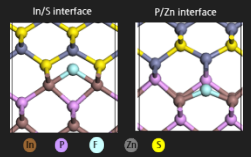
ZnS rich

2. Oxide interfaces
: Induce oxidative layer
*(*P)*

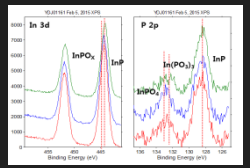
Multiple metal precursors
*(*US)*







(1-2) Gradient shell composition → minimize the lattice mismatch
*(*P)*



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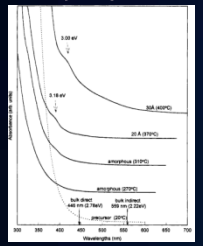
Potential materials

Other III-V semiconductor QDs and 2D structures

JPC (1995) Nozik



GaP
Eg=2.78eV

JACS (2012) Kim

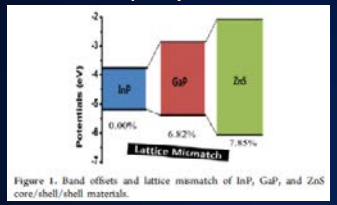
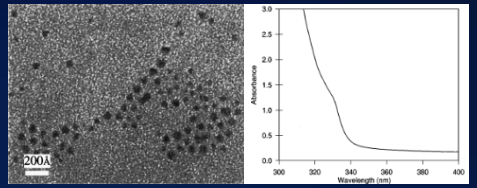


Figure 1. Band offsets and lattice mismatch of InP, GaP, and ZnS core/shell/shell materials.

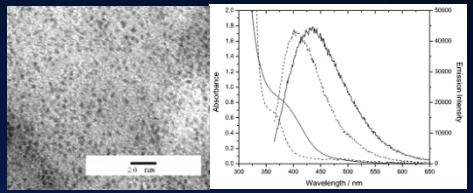
ZnInP/GaP/ZnS

APL(1999) Nozik



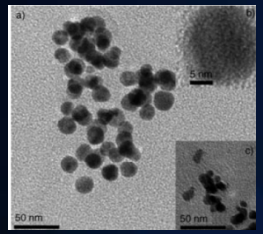
GaN, Abs 360~450nm

NL (2002) Kelley



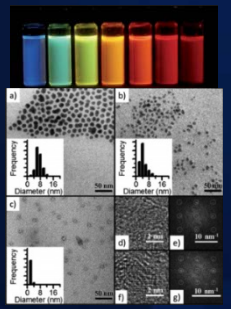
GaSe, Abs 360~450nm

Small (2005) Rao



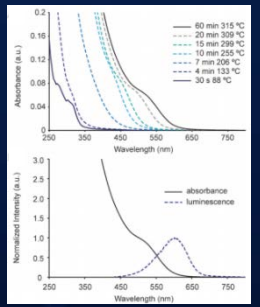
InN
Eg=0.65~0.7eV

JMC (2014) Taylor



Zn3N2
PL=500~1100nm
QY=52%(566nm)

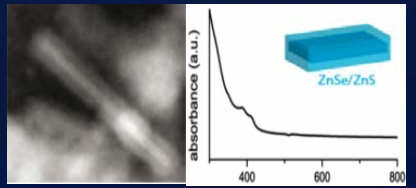
Chem. Comm. (2015) Cossairt



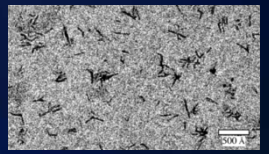
Zn3P2
PL=424~535nm
tetragonal

2D structure

CM(2014) Dubertret



NL (2003) Nozik



InP quantum rod

ZnSe nanoplate
Cation exchange from CdSe

Mass Production

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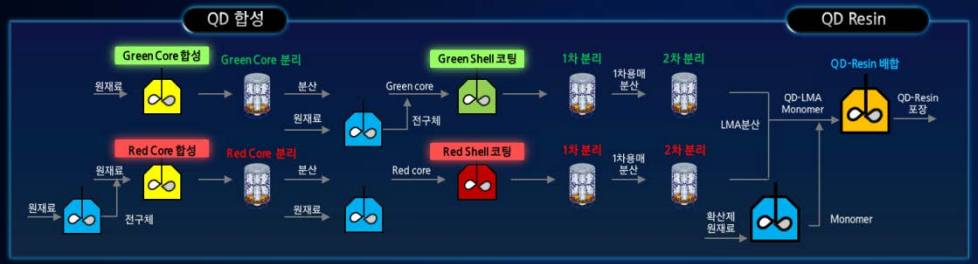
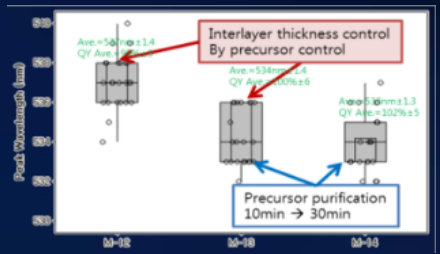
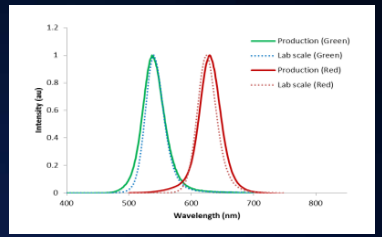
- **Process Optimization → Basic design → Scale-up**

Parameters: Precursors, Intermediates, Solvents, Surfactants, Additives, Reaction Process







ref. Courtesy of Hansol Chemical Corp.

20L

100L Pilot

Mass Production

QD Backlights (Film)

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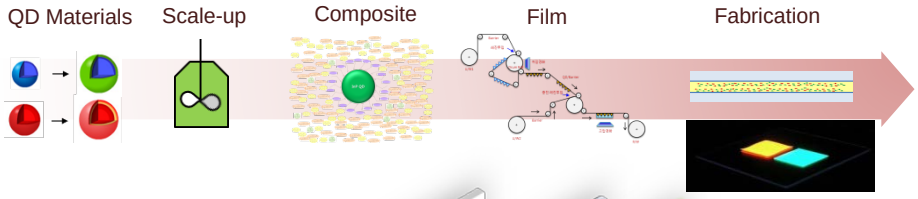
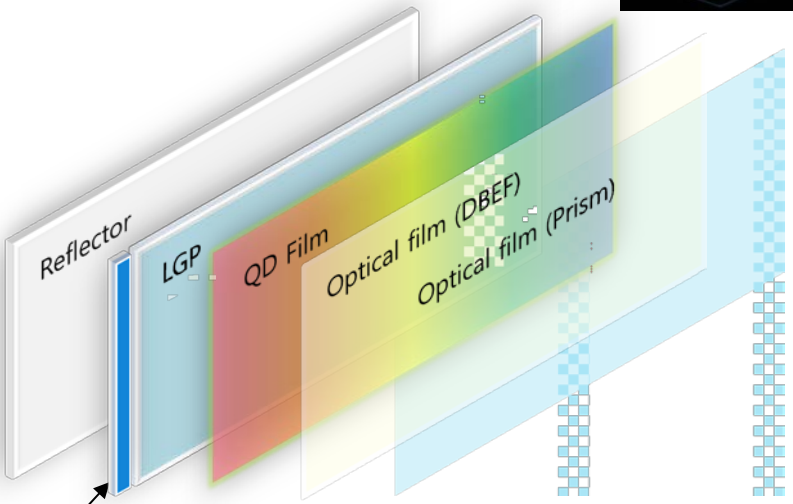
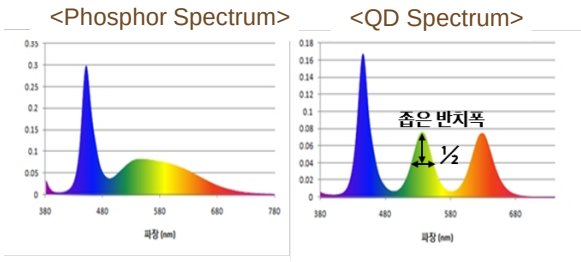
- **Wide color gamut display → Improve FWHM, Reduce cost**

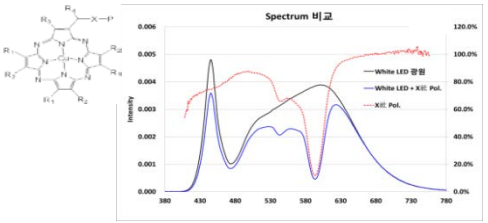




<LCD structure with QD Film>

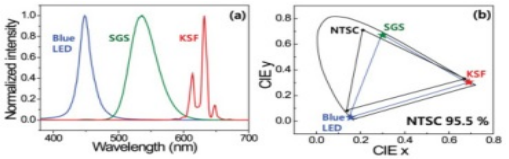


Organic dye (Color filter)



White LED BLU
Organic Dye
Transmitted BLU

Narrow bandwidth KSF phosphor



Optics Express Vol. 23, A791 (2015)

Accelerating R&D Process

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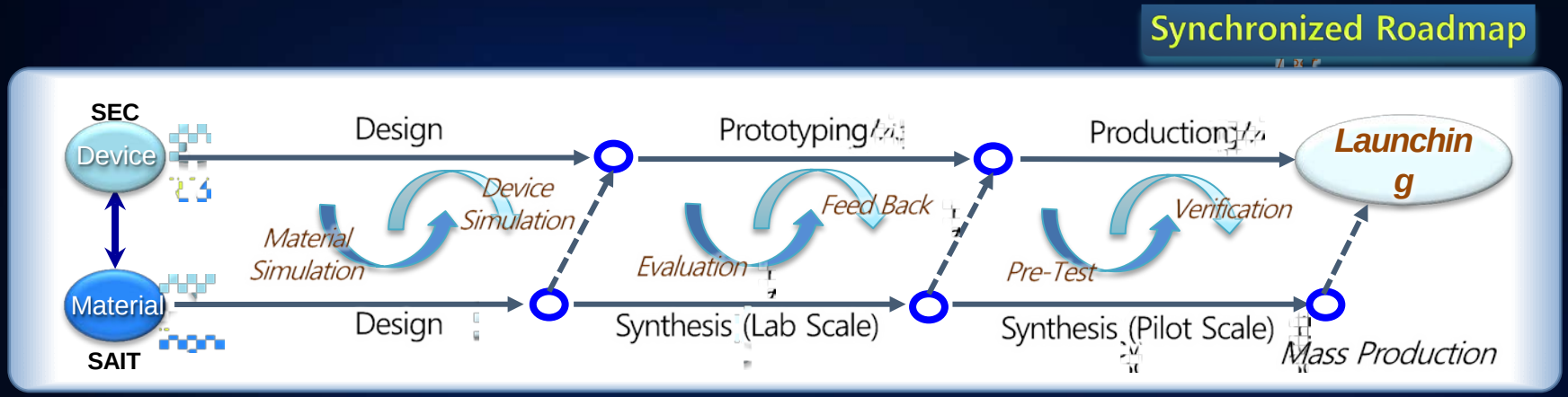
- Synchronize Technology Roadmap from the beginning stage of research

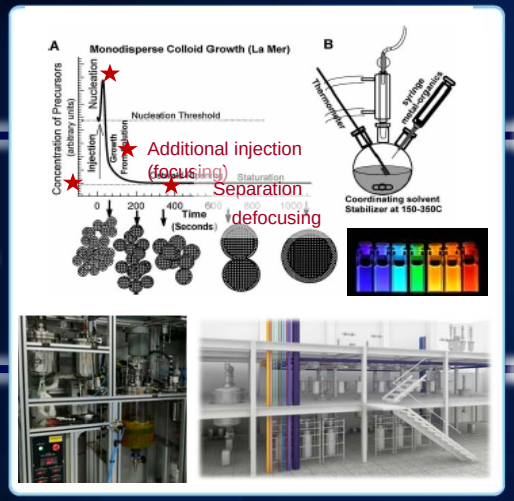


ref. H. Chang, MRS 2014 Fall Meeting

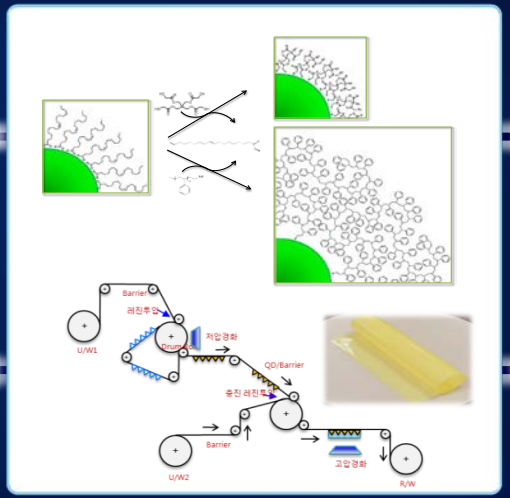
Development Team

- **Environmental Issues, Market size, Cost, Eco system, Patent portfolio**

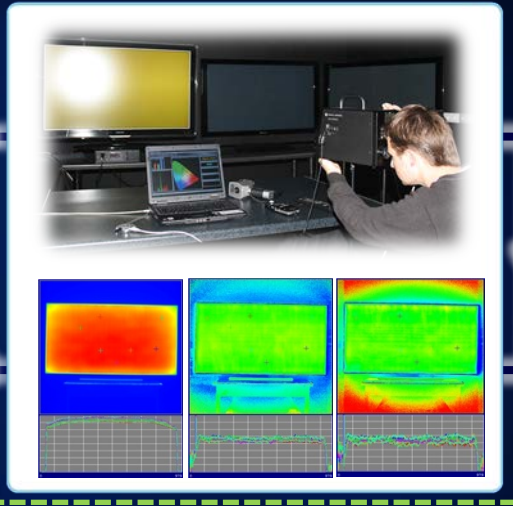
Material Design & Synthesis



Interface Design & Fabrication



Device Application & Evaluation



- Multi shell passivation
- Mass production
- Encapsulation (stability)
- Process stability
- Customer requirements
- Supply chain/Eco system

The Next Innovation in TV: QLED

Wide color gamut display with Cd-free quantum dot

Improvements in InP QDs

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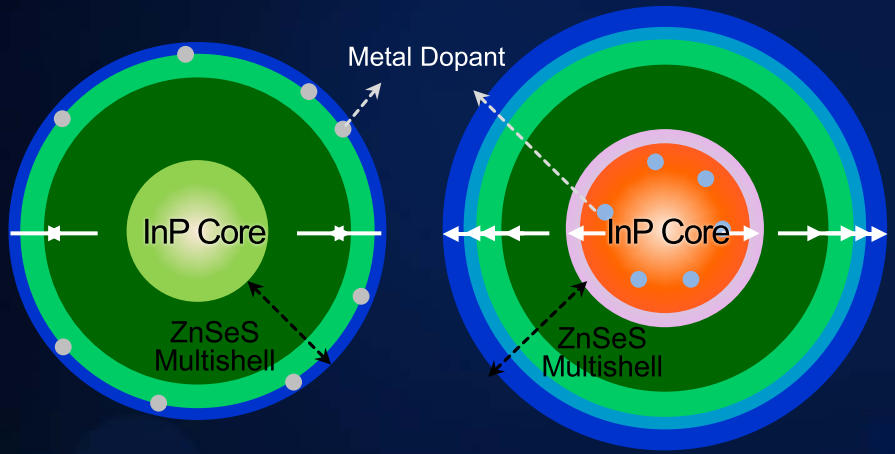
- **Optimized structure for uniformity and efficiency → BT2020, High stability**

Gradient Multishell/Metal Dopant

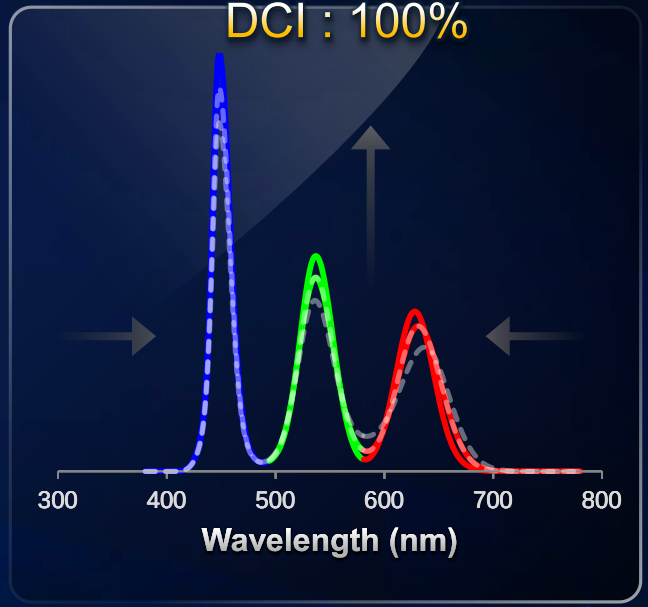


Green QD

Red QD

Brightness : 120%

DCI : 100%



QD Film

Structure of LCD

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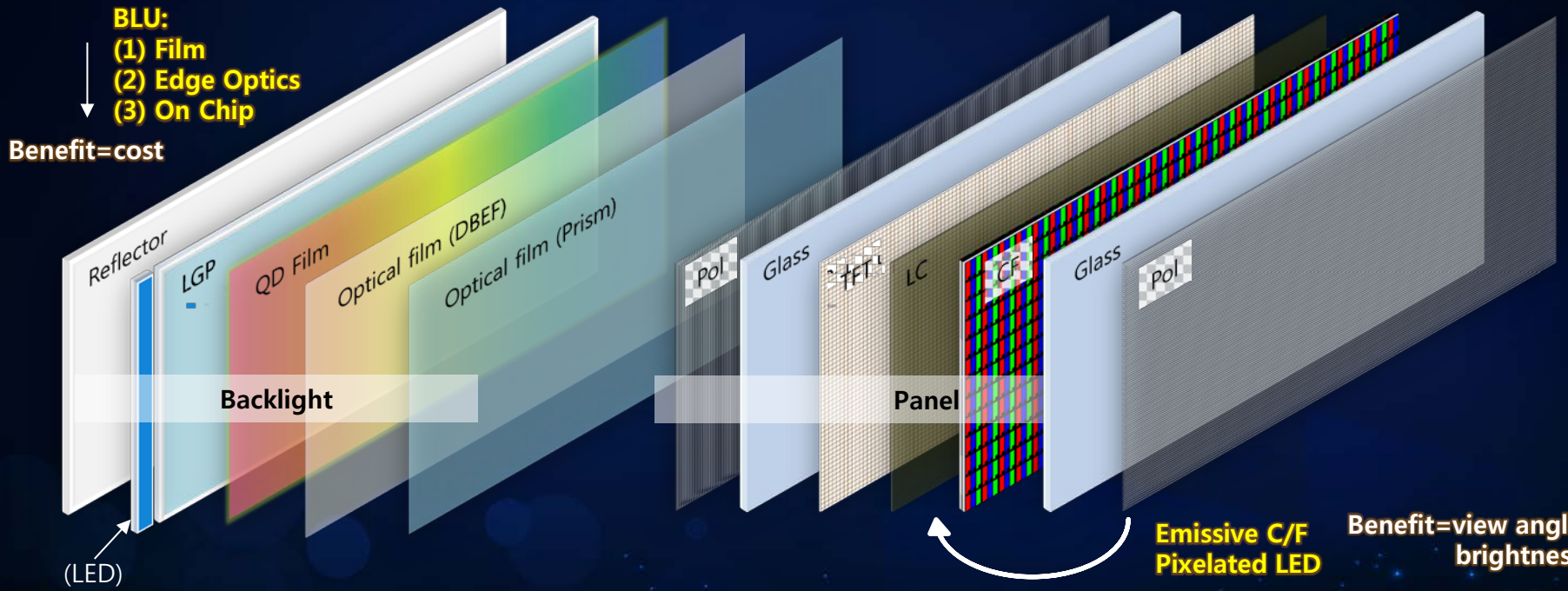
- Solve the disadvantages (Viewing angle, Contrast)



On-chip QD-LED

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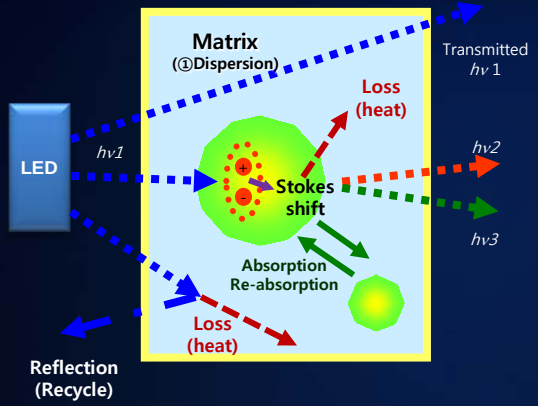
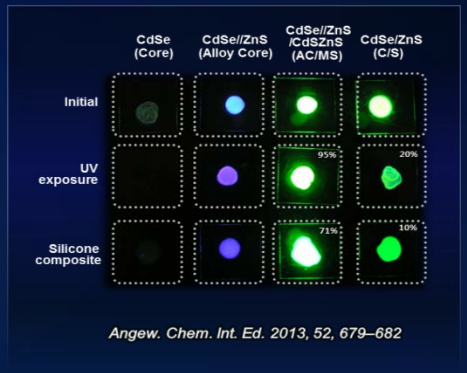
- Challenge in stability, PL quenching, Emission shift, and packaging

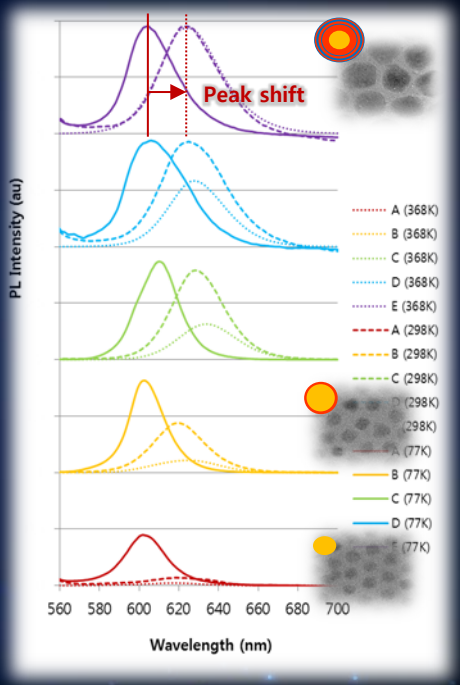


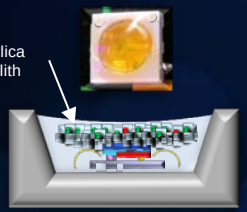
② PL quenching



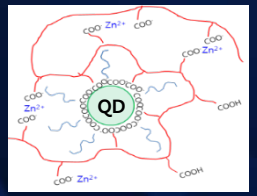
Angew. Chem. Int. Ed. 2013, 52, 679–682

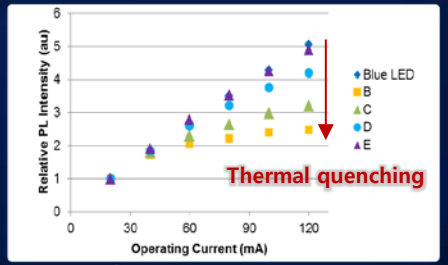
③ Thermal quenching





ACS Nano (2013) 1472





QD Color Filter

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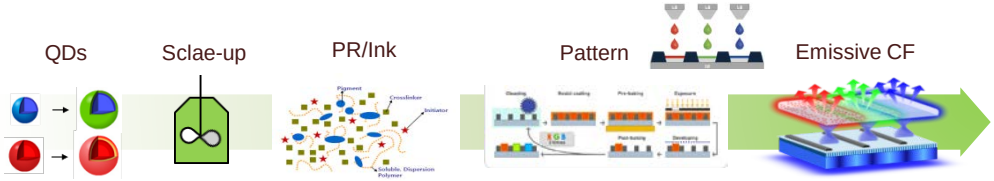
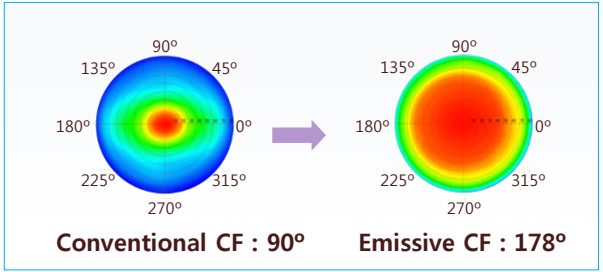
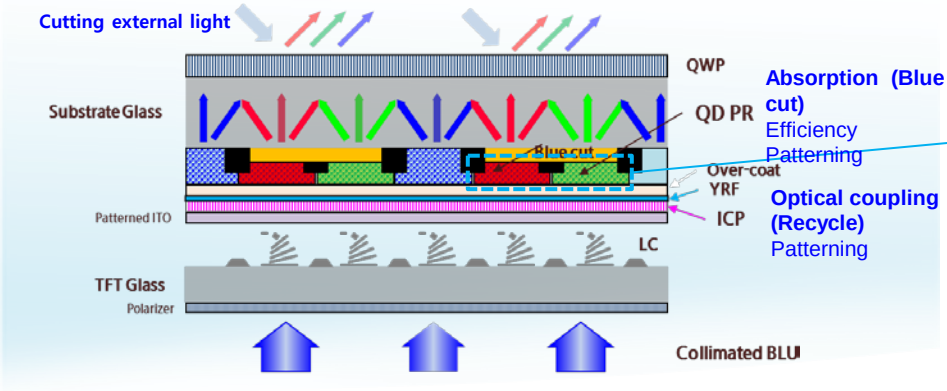
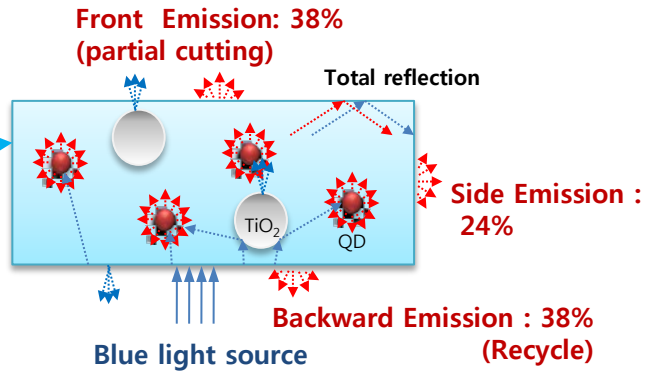
Perfect viewing angle (Emissive CF)





EQE = Absorption x QY $_{initial}$ x PL $_{quenching}$ x Thermal $_{quenching}$ x Out-coupling





QD-LEDs

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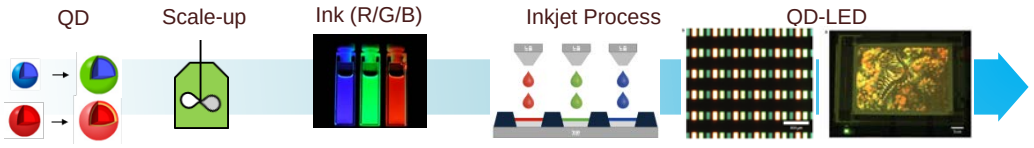
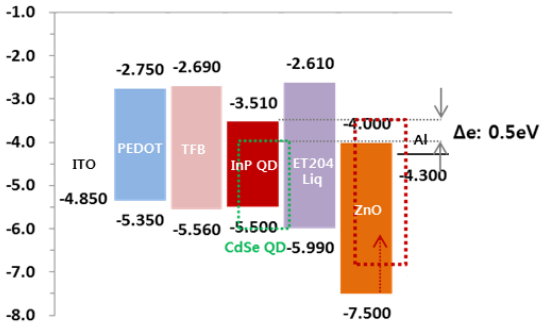
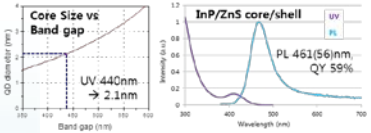
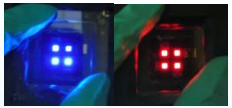
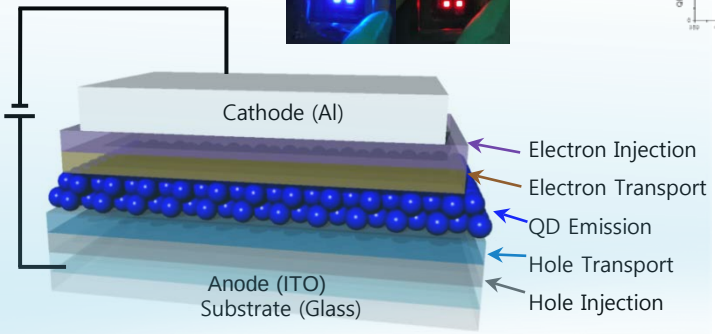
Better contrast (Pixelated RGB LED)



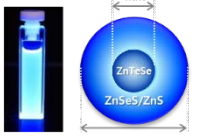


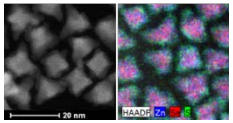




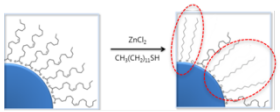


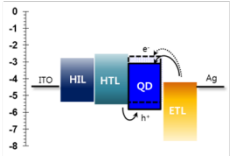
<Blue QD Synthesis>



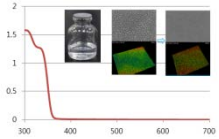


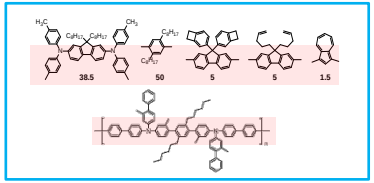
<Ligand Exchange>





<ETL/HTL Design>





Applications

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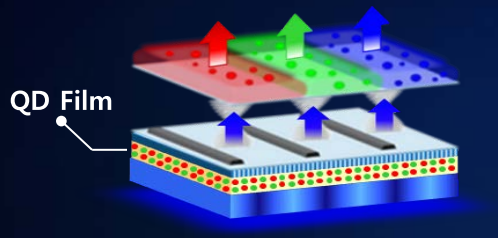
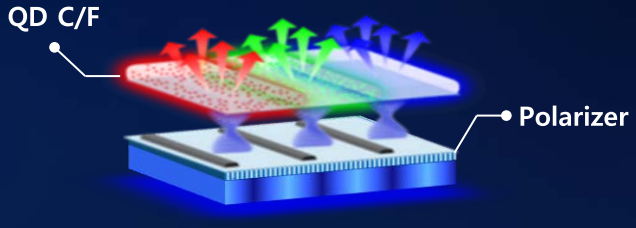
Expansion of technology based on QDs



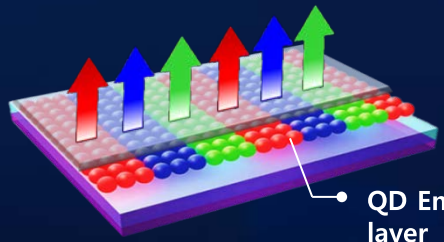
Film



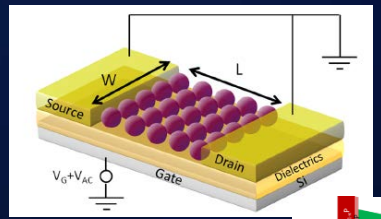
Color Filter

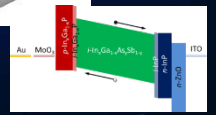
Color Conversion

Current driven



LED





NIR-Detector

Patterning

Acknowledgement

#Samsung
/ VD
/ SDI
/ SDC

#Hansol Chemical


Thank you
Q & A